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The Fractal Antenna

A Revolutionary Idea

Fractals are mathematical functions. This concept is normally connected with computer-generated images. Fractals became extremely popular in the eighties for two reasons: the first factor was the meteoric development of micro-informatics and the rapid increase in the computational power of micro-computers! The second contributing factor was the work of the world-renowned French mathematician, Benoît Mandelbrot, who had made his name working in the field of fractals.

1.

Order and chaos

Fractals were originailly just a mathematical concept. Since then, they have become a tool which allows splendid images to be generated by computers. But thats not all they also offer a general concept of the universe, a unifying principle of science, thanks to Benoît Mandelbrot and numerous other researchers.

Fractals are linked to chaos theory. In 1988, a book was published called "CHAOS" by James Gleick , and became very popular. It includes several astonishing propositions which have since become common knowledge; like the one about the butterfly in China which flaps its wings and, through a chain of chaotic events, subsequently causes a tornado in the Caribbean.

Fractals combine order and disorder in a unique way! If we look attentively at one of the illustrations in Fig. 1 above, we can see that they are disordered within a small frame and yet ordered on a large scale. A fractal can be chaotic, as in these diagrams, or deterministic. "Deterministic" here means that they are composed on the basis of a single pattern (for example a triangle or a rectangle), which is called the generator, and that they are based on successively changing scales (which are called "repetitions"). The number of repetitions can be infinite. You need at least two of them to be able to speak of self-similarity. Examples of fractals are the Koch curve, Fig. 2 on the left, the Sierpinski triangle, or the "cylinder head gasket" developed by Mandelbrot, Fig. 2 below.

The term "fractal" was coined by Benoît Mandelbrot. It means that it can be proven that fractal images have no complete dimensions i.e. they are incomplete. This does not happen in Euclidian geometry! In classical geometry, a point is defined as having no dimensions. A line has one dimension, a plane has two and finally a volume has three dimensions. So far so good. It can be demonstrated that a given fractal, for example

log 4 / log 3 = 1.2618 dimensions

or again

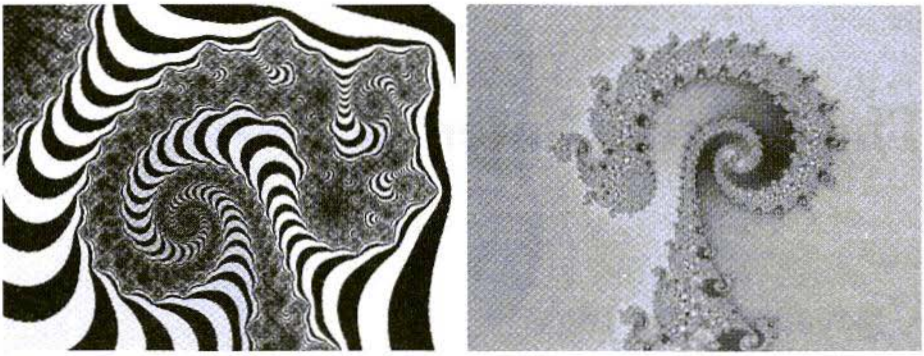

Fig 1: Two examples of Fractals

log 2 / log 3 = 0.6309 dimensions! This point can be understood intuitively. If, for example, we take a Sierpinski triangle, this is an area, so it has two dimensions. For the first repetition, a triangle is removed from the whole and here again we find once more three smaller triangles, but these also still have two dimensions. If we repeat this procedure in stages, the areas become smaller and smaller. After an infinite number of repetitions, the triangle will be made up of an innumerable number of areas which will be infinitely small. The entire area will be approaching zero, but nevertheless the Sierpinski triangle appears to possess an area. It can be mathematically demonstrated that the number of dimensions is less than two.

2.

From theory to practise

The subject of this article is the application of the theory of fractals to the design of antennas. The objective is not simply to discuss a modern subject but to demonstrate that there really is some potential here. Researchers have already investigated this path extensively and have established that the theory of fractals makes it possible to create much more powerful antennas (with regard to the size, radiation efficiency, antenna efficiency and band width or slight side lobes). There are some antennas which can just not be designed without fractals.

Fractal antennas are a new area of development only 4 or 5 years old; for this reason, there are very few descriptions to be found. Fig. 3 shows two industrial developments which have already been produced.

This area of development looks very promising against the background of an enormous expansion in wireless communication. The developers are working away at it intensively and protecting their own developments through patents. However, little by little it is becoming possible to get at the secrets of even this new type of antenna. This article is already a beginning.

3.

Characteristics of a fractal

To obtain some idea of what a fractal is, try and answer the following question: how long is the coast of Corsica? That seems to be an easy question. All you need to do is find a map of Corsica and pick up a ruler - right? Wrong!

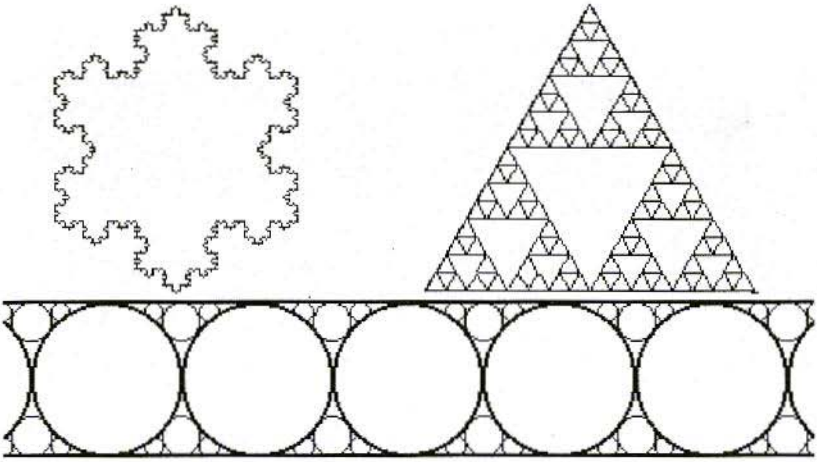

Fig 2 : Examples of the Koch Curve, the Spierpinski Triangle and the Cylinder Head Gasket developed by Mandelbrot

You take a large-scale map and a pair of compasses. Working from the scale of the map, set the points, e.g. to 50 km and then measure, approximately, the length of the Corsican coastline. Now repeat the process once more, but this time set the compass points to 5 km. Since the coastline is very jagged and consists of numerous promontories and bays, the value now obtained will be greater than the first result. If we use more and more detailed maps and smaller and smaller measurement steps, the value at each stage will be greater than the preceding value. We would thus finally arrive, in theory, at an infinite length.

It could be said that this theoretical contour of Corsica is a fractal diagram; it gives us a coastline with an infinite number of indentations. They all look the same, irrespective of whether they extend 1 km, or 10 or 100 km . Incidentally, the same also applies to a cloud. There are also computer programs which apply fractal theory to the synthetic generation of landscapes. And take it from me, I can confidently assert that these synthetic landscapes (Fig. 4) look more "realistic" than reality!

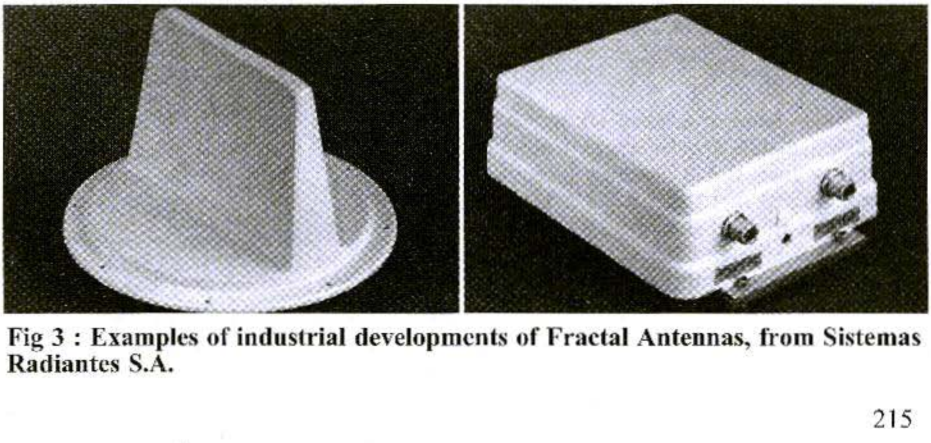

Fig 3 : Examples of industrial developments of Fractal Antennas, from Sistemas Radiantes S.A.

Fig 4: A Fracal Landscape, produced with software called "Bryce" from R. Vanderlippe

And so we come to a characteristic which can be extremely valuable for an antenna it always behaves the same way with waves of varying wavelengths, irrespective of whether the wavelength is 10 cm, 1 m or 10 m. In other words, a wide band antenna.

If we use a dipole which has a fractal form instead of the standard rectilinear form, we can establish that it is made up of a large number of sections, each of different length, and that each will radiate in a certain part of the spectrum as well as possible (Fig. 5).

On the other hand, everyone knows that the shortest distance between two points is a straight line. But it has now likewise been recognised that the longest distance is the fractal line! In this way, we obtain curved radiating elements which result in very much more compact antennas with less losses and a higher degree of efficiency. Fig. 6

Another possible way of using the theory of fractals is the log periodic antenna; it is well-known for its extensive band width. In a log periodic antenna, the theory of fractals is applied, not just to the individual elements but to the entire architecture of the antenna. Although it had already been invented many years

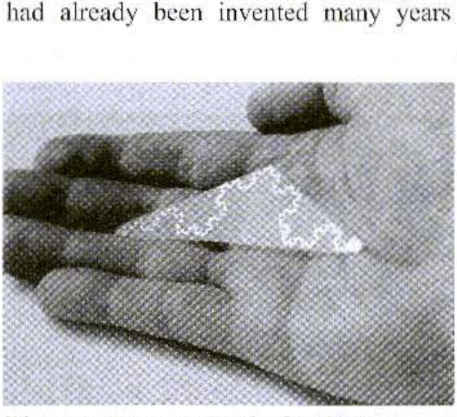

Fig 5: A Fractal dipole developed using the Koch curve by Nathan Cohen - N1IR

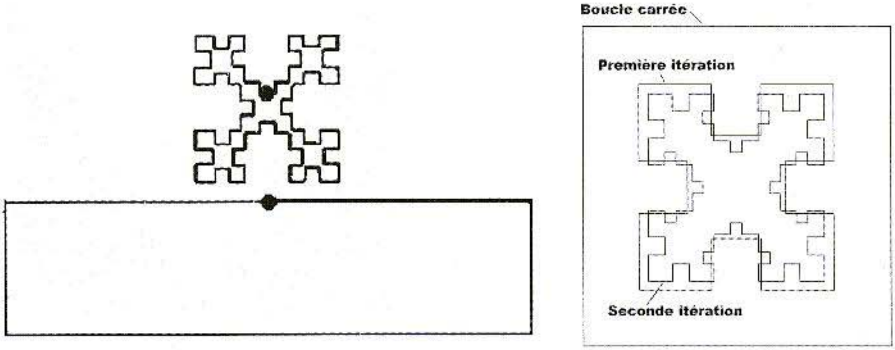

Fig 6: The development of the Fractal form of a rectangle. The right hand side shows the iteration process.

ago, before there was any talk of fractals, it can be recognised that it has one of their essential characteristics: self-similarity. This is one characteristic property which immediately strikes anyone who sees a fractal image. What this observer sees is one element repeated infinitely, from the tiniest detail right up to the overall view. Like the marmelade jar on which there is a label with a photo of a little girl holding a marmelade jar, on which there is a photo of a little girl - etc..

It can be demonstrated mathematically that, for an antenna to have good broadband functioning, it must have a point of symmetry and it must be self-similar. I.e., its appearance must always be the same, irrespective of the scale. In other words, it must obey the law of fractals.

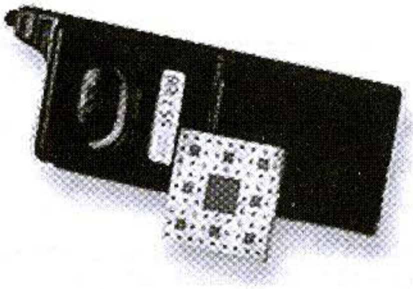

Fig 7: A Fractal antenna developed for a mobile phone by Nathan Cohen - N1IR

Various well-known fractal representations, such as the Sierpinski triangle, have been put forward as antennas. The common point of all these structures is their good behaviour in relation to their reactivity, which usually means we can do without any matching. This implies a simplification of design, greater reliability and lower losses.

It is possible to create radiating fractal structures for the UHF range as printed circuits. In the ultra-short wave range as well, thanks to the good ratio of the wavelength to the mechanical length with this approach, printed circuit structures can be used (Fig. 7).

There are structures drafted in one piece, but there are also antennas consisting of a metallic plane, in which holes have been stamped in accordance with fractal distribution.

The concept of fractal antennas can be applied to individual antennas or to antenna arrays. In the case of arrays, the

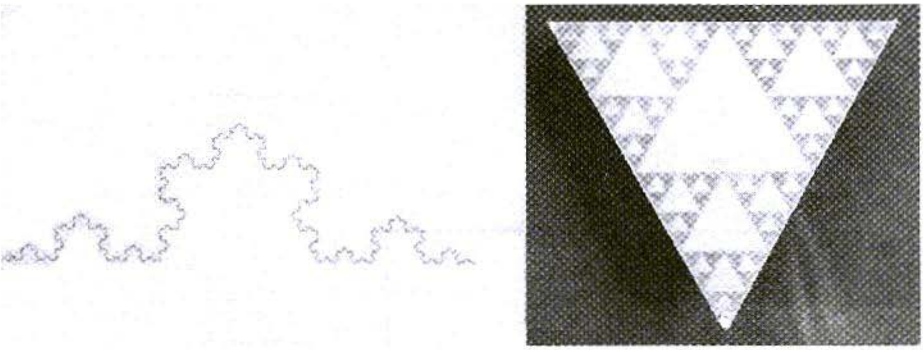

Fig 8: Right - a Koch curve, Left - A Sierpinski triangle developed as a printed circuit by The Carles Puente Polytechnic at Barcelona University

distribution of elements can be regular, as in certain radar antennas, or irregular, as in certain radio telescope arrays, which were built by linking together already existing instruments, which are distributed all over the world.

A fractal array can combine the robustness of an irregular array with the efficiency of a regular array, and this with only a quarter of the elements.

In the case of individual antennas we can, as an example, take the Koch curve or the Sierpinski triangle (Fig. 8).

These representations, e.g. of the coiled shape, combine inductances and capacitances, which removes the need for any matching circuit and extends the transmission band, in that it improves the gain. Antennas have already been put on the market which can advantageously replace the rubber antennas of portable equipment. Some have been created using small printed circuits which are integrated into the housing of a mobile phone.

It is true that fractal antennas allow miniaturisation, but we should not go beyond a reduction in size by a factor of 2 to 4. Otherwise there is a danger of sacrificing the yield. And, just as with all other antennas, it will naturally not be possible to have small dimensions, large band widths and high gain simultaneously. But fractal antennas can come closer to this than other types and thoroughly successful compromises can be obtained between these three characteristics.

Any type of antenna can be fractalised: monopole, dipole, helix, printed antennas, etc.. The elements are formed in accordance with a fractal representation, or gaps are introduced into the antenna.

In the case of flat antennas such as printed circuits, which are made up of several elements, the coupling between them is generally the main factor which restricts their power i.e. gain and their impedance matching. This problem is avoided in the case of the fractal antennas.

4.

Experimental fractalisation of a loop

Nathan Cohen, N1IR, had the following experience: he manufactured a frame antenna with an edge length of 15 centimetres, in the form of a rectangular printed circuit. He then manufactured three other fractalised antennas with the same dimen-

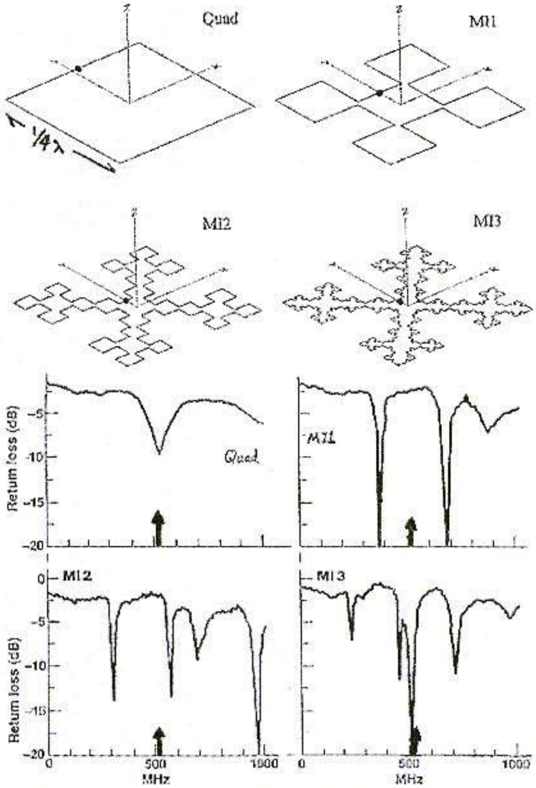

Fig 9: Experimental results on a Quad Loop by Nathan Cohen - N1IR

sions, but each time adding a repetition in accordance with the Koch curve. Naturally the size of the loop went up each time.

Compare this with the problem of the Corsican coast which we mentioned earlier. He then measured the reflected power (proportional to the SWR) of each of these antennas. This told him that the frequencies at which the SWR was lowest (which means that the impedance here was approximately 50 Ohms) kept changing, and that the more peaks there were on the frequency axis the lower these were (Fig. 9).

For antennas with three repetitions, for example, we have a usable peak at one-third of the frequency of the non-fractalised loop. It should be borne in mind that the peaks are not harmonics of the start frequency. It can be determined subsequently that the peaks also correspond to zones in which the impedance is real i.e. not reactive. If the radiation resistance is at 50 Ohms and is not reactive, that means that no additional matching is necessary.

5.

Fractalisation of a dipole

In this example we are not dealing with experiments but with the results which were calculated by Nathan Cohen, N1IR,

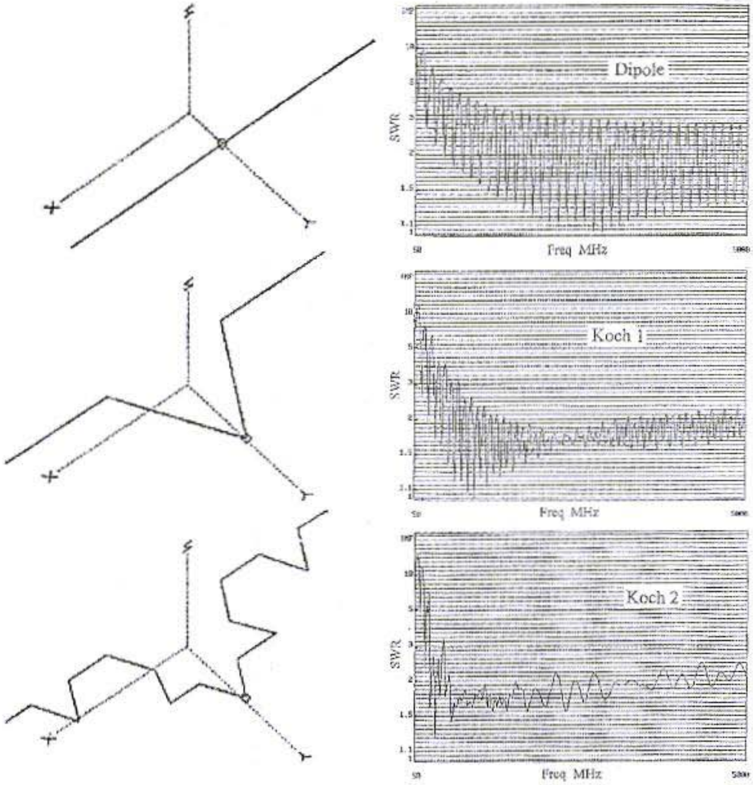

Fig 10: Fractal Dipoles by Nathan Cohen - N1IR

with the help of "NEC4" software (Fig. 10).

Here, instead of a loop, we take a dipole dimensioned for 65 MHz, to which we apply two repetitions of the Koch pattern in succession. But this time we sweep a much bigger range, going right up to 5 GHz. With a rectilinear dipole we now measure a host of points with a low SWR for all harmonics of 65 MHz.

On the other hand, the fractalised dipoles demonstrate expansion and lower troughs. The optimal impedance i.e., for which the trough is weakest lies around 350 Ohms.

Thus we can see that fractalisation can be used to create antennas with an extremely wide transmission band.

6.

Practical Applications

A practical application of the fractal theory has been put forward by Nathan Cohen, N1IR: a quad with two elements for the 10-m-Band. Fig. 11

It measures 1.5 m x 1.5 m without any efficiency losses as against the unfractalised version. It does not need a matching circuit, and its impedance, Z, is 50 Ohms. It can thus be energised directly through a coaxial cable. Fig 12.

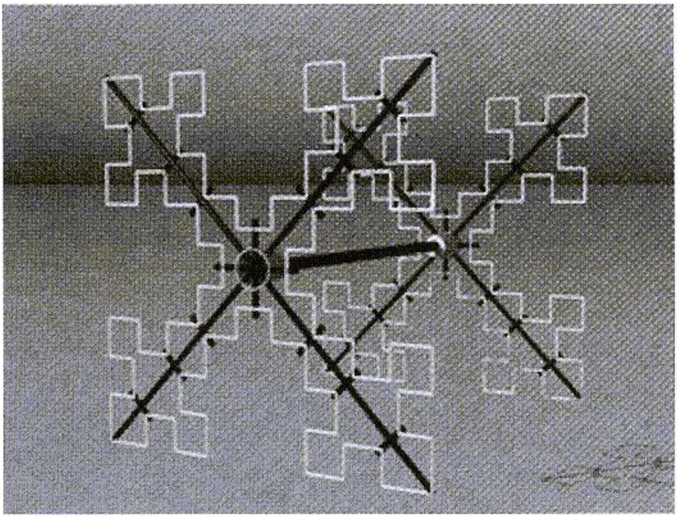

Fig 11: A Two Element Quad for the 10 m band by Nathan Cohen - N1IR

Using this antenna, radio contact could be made with European locations at 1 Watt and with the Pacific region at 2 Watts. A further version was measured for the 2-m band, with a gain of 4 dB and a front-to-back ratio of at least 15 dB. The 2-m version has a transmission band width of 500 kHz with an SWR below 2.

Fig. 14 shows a general view of the antennas. The two elements have the same dimensions. They can be manufactured using copper wire (1.5 mm. or more). The simplest method is to use a template on a wooden board on which nails are knocked in at the bending points, 1 to 26, in accordance with the pattern, and the copper wire can thus be very precisely bent. Each of the four sides of an element is bent on the template in succession in this way.

Fig. 13 shows a quad element for 10 m with corresponding dimensional specifications. The framework of the quad can easily be manufactured using PVC tubing. The same material can be used for the transverse struts. The typical impedance of the antenna can be increased if the length of the middle transverse struts is increased.

Instead of the coax cable, a coil with two turns is connected to the distributing point of the reflector, so that its frequency of resonance can be decreased by app. 600 kHz. The distance between the active element and the reflector is 170 cm.

Like all fractal antennas, this antenna is also resonant in more than one band. N1IR detected resonances at 52, 97, 125 and 141 MHz. At 125 MHz, the front-to-back ratio is 10 dB and the gain is likewise 10 dB, which is a lot for an antenna which is contained in a cube with a wavelength of only 0.6.

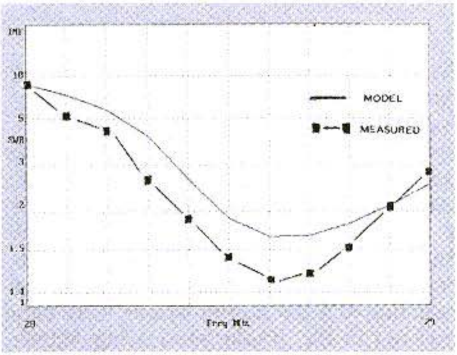

Fig 12: The measured and theoretical SWR for the Two Element Quad

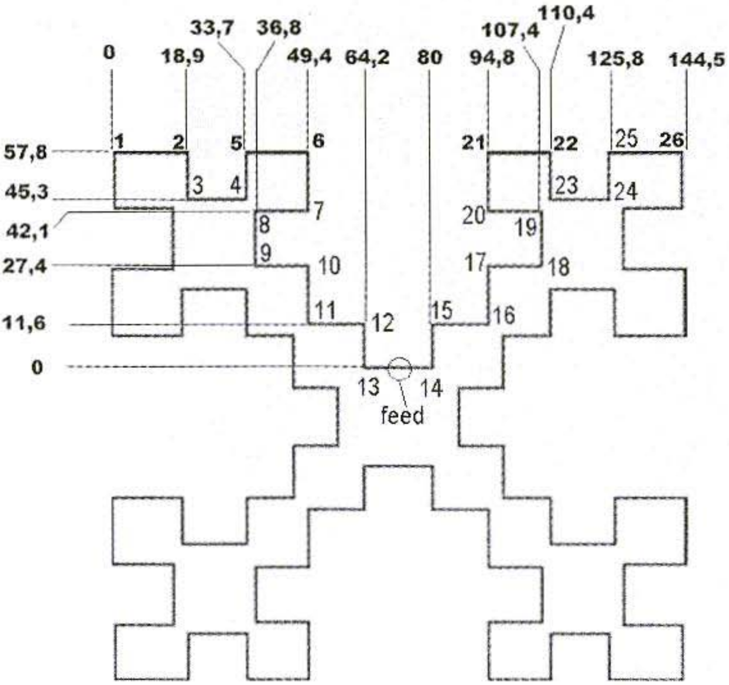

Fig 13: Dimensions for the Two Element Quad

6.1. Two fractal antennas for the 70-cm band

Another practical implementation for the American 70-cm band is proposed by Richard Kutter of the University of Dayton. To demonstrate the validity of the concept of the fractal antenna, he first examined a dipole and an antenna proved a tempting control. He then compared them with two fractalised loops, one with one repetition, the other with two. The radiation and SWR simulations were carried out in the 70-cm band using MININEC Pro. To ensure that the fractalised antennas remained in the desired band, their dimensions were matched. He simulated the properties of two quad antennas with two, then with three loops (Fig 15 and 16). Unfortunately he gives no details of the precise dimensions of his antennas.

6.2. Fractal antennas for microwaves

The higher the frequency involved, the fewer details we are given by authors. It is, in fact, in the ranges of mobile telephony and microwaves that the applications are most interesting from the commercial point of view...

Here are some examples of ultra-high frequency antennas, on which numerous

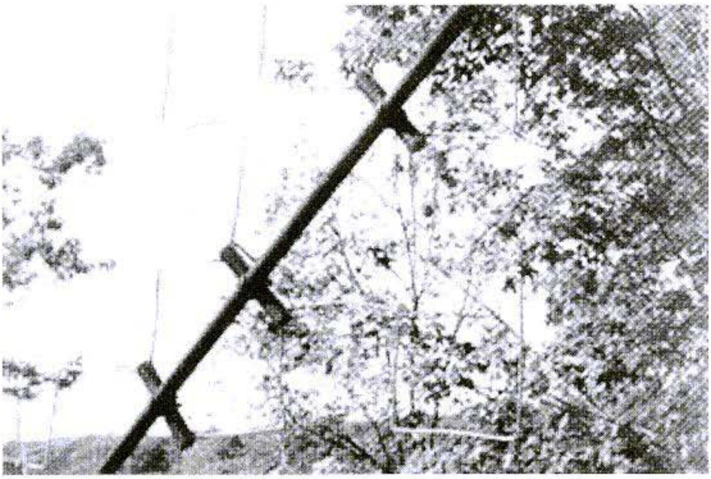

Fig 14: A picture of the Two Element Quad antenna for the 10 m band

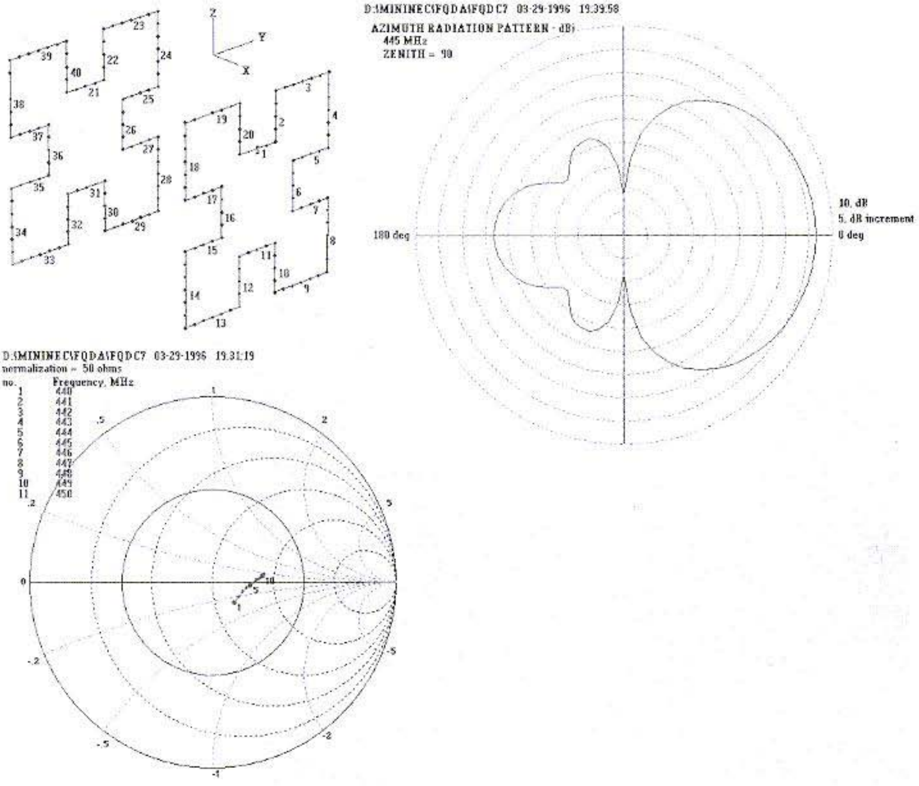

Fig 15: Simulation of a Two Element Quad for the 70 cm band

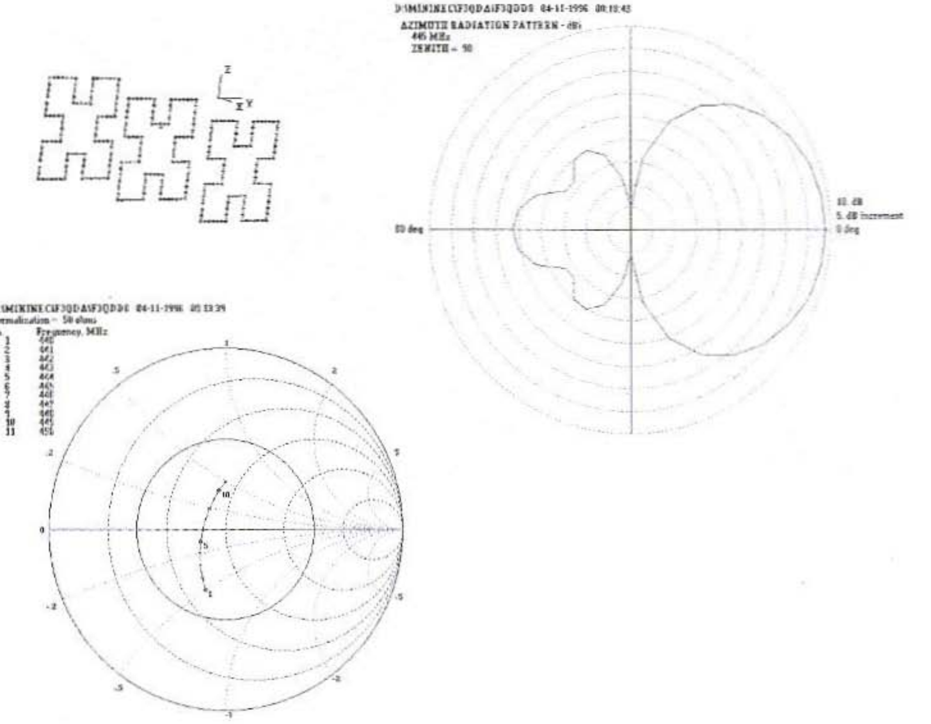

Fig 16: Simulation of a Two Element Quad for the 70 cm band

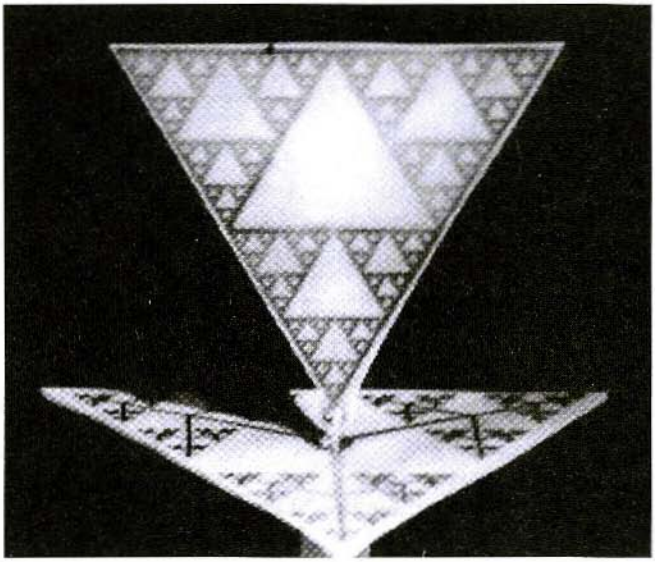

Fig 17: The Sierpinski Triangle used at microwave frequencies

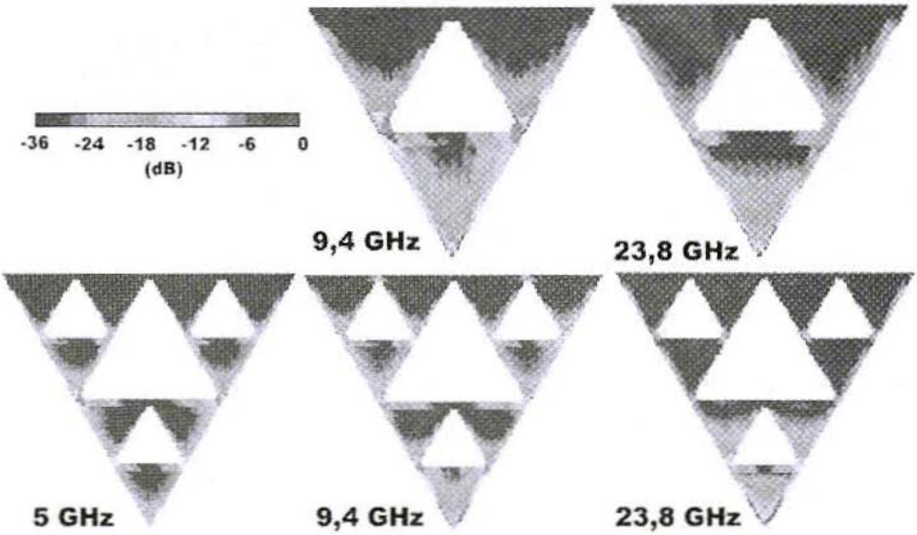

Fig 18: Examples of antennas scaled for various microwave frequencies

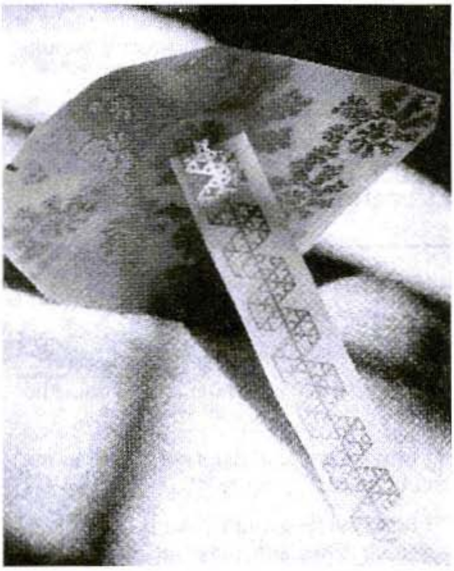

Fig 19: A wideband antenna developed by Nathan Cohen - N1IR

Fig 20: A Fractal version of the helix antenna by Nathan Cohen - N1IR

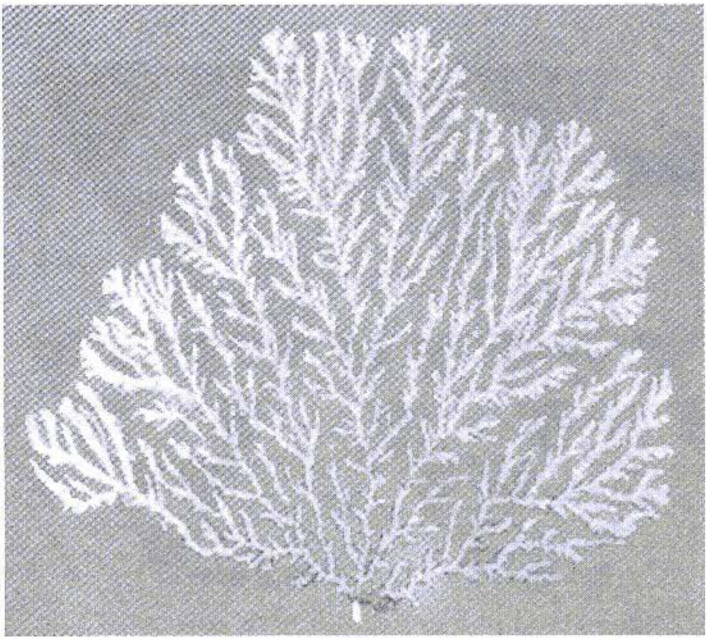

Fig 21: My Favourite, a beam antenna developed by The Carles Puente Polytechnic at Barcelona University

teams are currently at work all over the world. But, who knows? Perhaps, once again, another important discovery will emerge from the amateur radio community?

6.3. The Sierpinski triangle

One structure often used in ultra-high frequency engineering is the Sierpinski triangle. It is powered through one of the corners, in that it is connected up to the internal conductor of a coaxial line. The screening is connected to the earth surface, which can be both a closed surface and also a fractal figure. The behaviour of such an antenna can be analysed with the help of software based on the moments method, such as, for example, EmSight. The program has already been introduced here. The said method makes it possible to calculate the intensity of the currents which prevail in the conductors.

The point of optimal matching for patch antennas is generally empirically determined. However, a start has been made on using mathematical models to develop simulations, which will certainly make it possible to create more powerful simulations in the coming years.

7.
Literature

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